

Lightning Forecast Algorithm (R3)



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GLM Science

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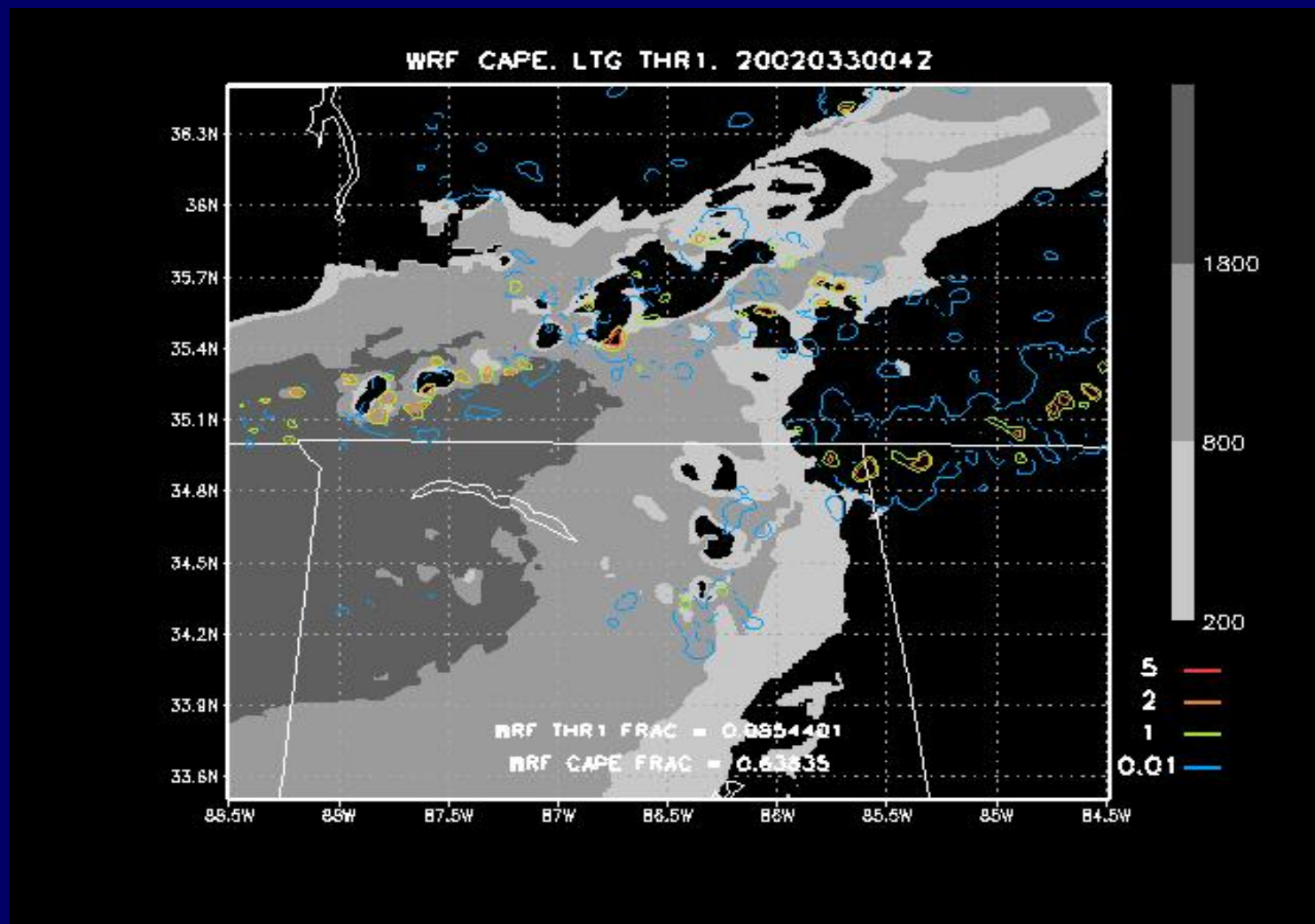
Photo, David Blankenship
Guntersville, Alabama



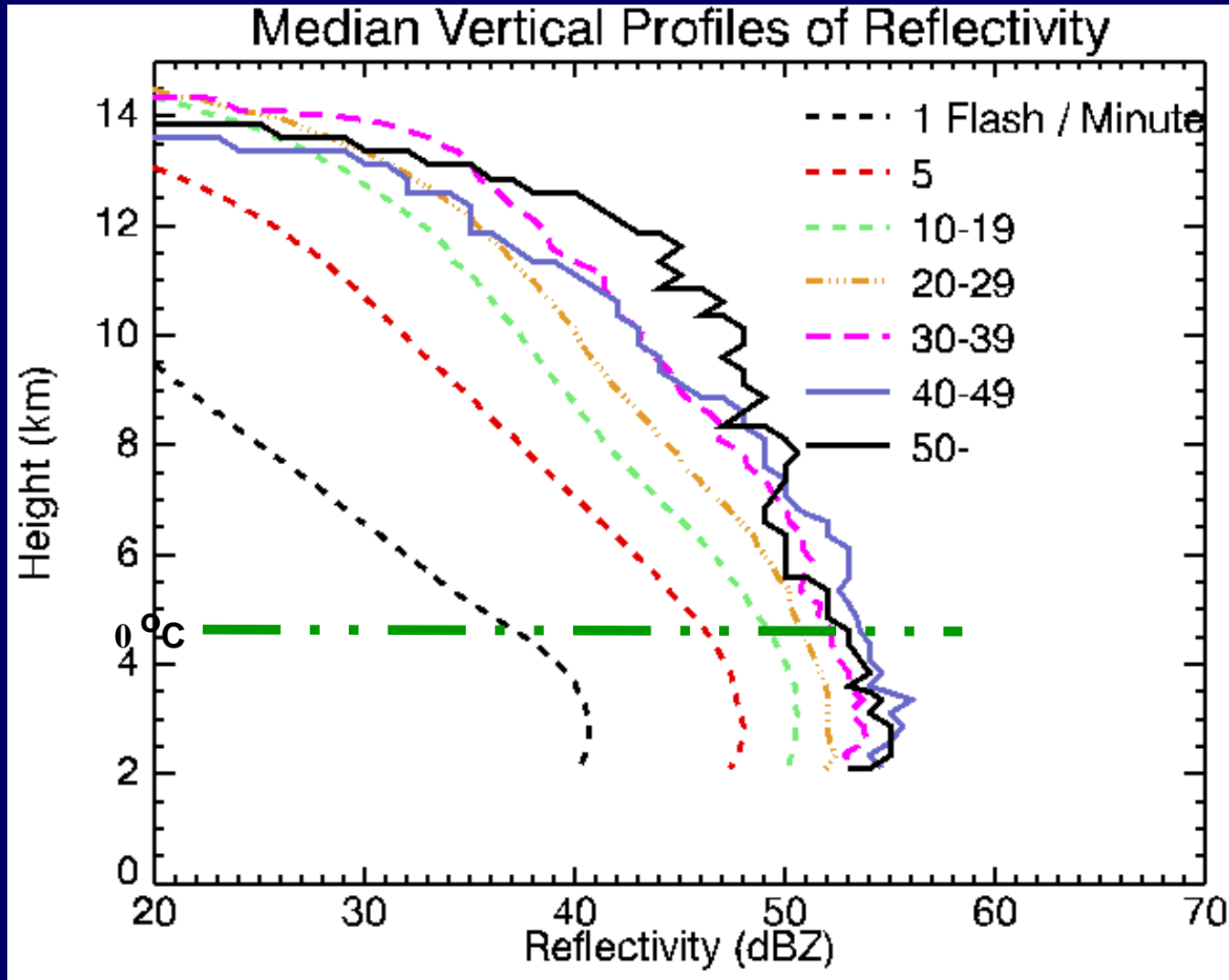
Background

1. high-resolution explicit convection WRF forecasts can capture the character and general timing and placement of convective outbreaks well;
2. traditional parameters used to forecast thunder, such as CAPE fields, often overestimate LTG threat area (see next page); CAPE thus must be considered valid only as an integral of threat over some ill-defined time;
3. no forward model for LTG available for DA now; thus search for model proxy fields for LTG is appropriate;
4. prior research using global TRMM data has shown that LTG flash rates depend on updraft, precip. ice amounts

Comparison of areal coverage: CAPE vs Threat 1



LIS flash rates vs TRMM dBZ, see Cecil et al. 2005





Objectives

Given the background cited above, we seek to:

1. Create WRF forecasts of LTG threat (1-24 h), based on two proxy fields from explicitly simulated convection:
 - graupel flux near -15 C (captures LTG time variability)
 - vertically integrated ice (captures anvil LTG area)
2. Construct a calibrated threat that yields accurate quantitative peak flash rate densities based on LMA total LTG data
3. Test algorithm over CONUS to assess robustness for use in making proxy LTG data, potential uses with DA

WRF Lightning Threat Forecasts:

Methodology

1. Use high-resolution 2-km WRF simulations to prognose convection for a diverse series of selected case studies
2. Evaluate graupel fluxes at -15C level; vertically integrated ice ($VII = \text{cloud ice} + \text{snow} + \text{graupel}$ in WSM-6)
3. Calibrate WRF LTG proxies using peak total LTG flash rate densities from NALMA vs. strongest simulated storms; relationships ~linear; regression line passes through origin
4. Truncate low threat values to make threat areal coverage match NALMA flash extent density obs
5. Blend proxies to achieve optimal performance
6. Study CAPS 4-km CONUS ensembles to evaluate performance, assess robustness



WRF Lightning Threat Forecasts:

Methodology

1. Regression results for threat 1 “ F_1 ” (based on graupel flux $FLX = w * q_g$ at $T = -15$ C):
 $F_1 = 0.042 * FLX$ (require $F_1 > 0.01$ fl/km²/5 min)
2. Regression results for threat 2 “ F_2 ” (based on VII, which uses cloud ice + snow + graupel from WRF WSM-6):
 $F_2 = 0.2 * VII$ (require $F_2 > 0.4$ fl/km²/5 min)

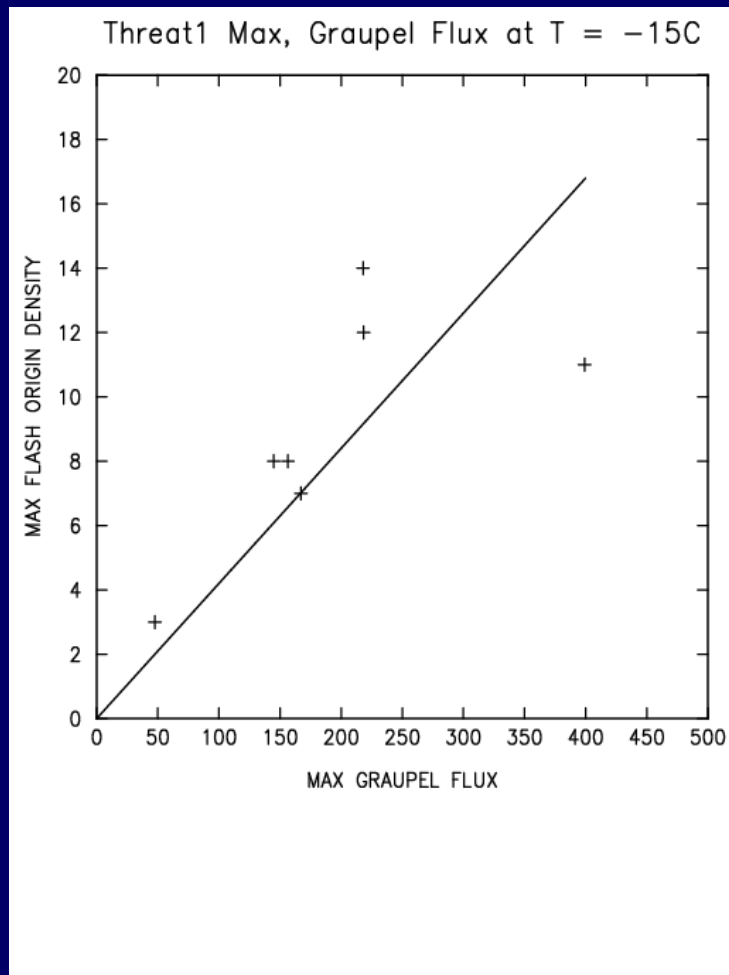
Calibration Curve

Threat 1 (Graupel flux)

$$F_1 = 0.042 \text{ FLX}$$

$$F_1 > 0.01 \text{ fl/5 min}$$

$$r = 0.67$$



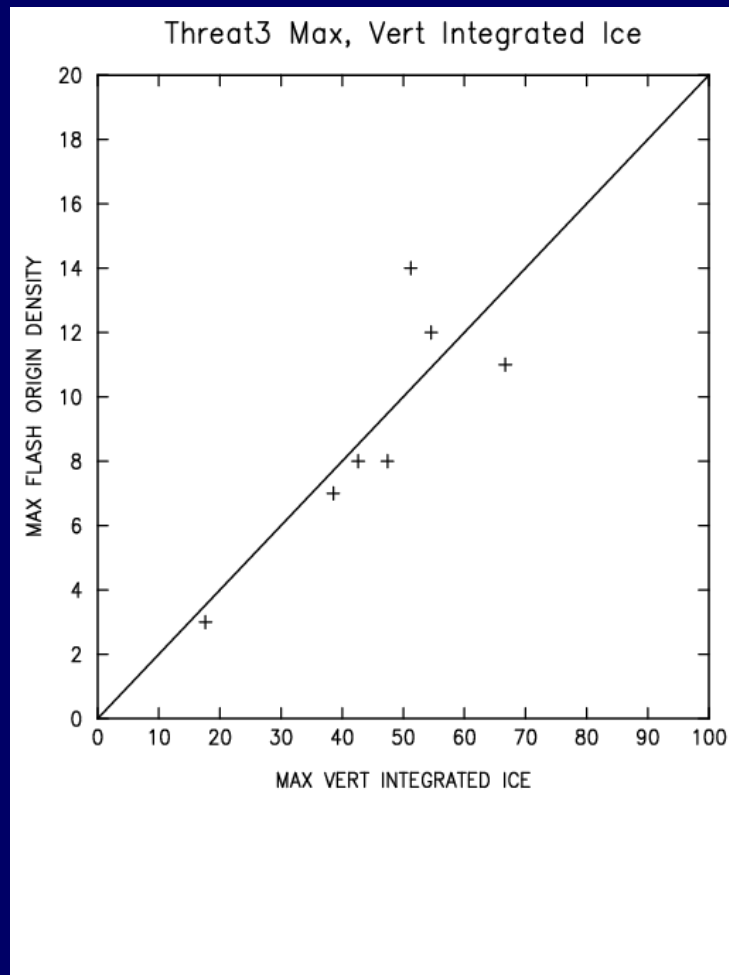
Calibration Curve

Threat 2 (VII)

$$F_2 = 0.2 \text{ VII}$$

$$F_2 > 0.4 \text{ fl/5 min}$$

$$r = 0.83$$





LTG Threat Methodology: Advantages

- Methods based on LTG physics; should be robust and regime-independent
- Can provide quantitative estimates of flash rate fields; use of thresholds allows for accurate threat areal coverage
- Methods are fast and simple; based on fundamental model output fields; no need for complex electrification modules



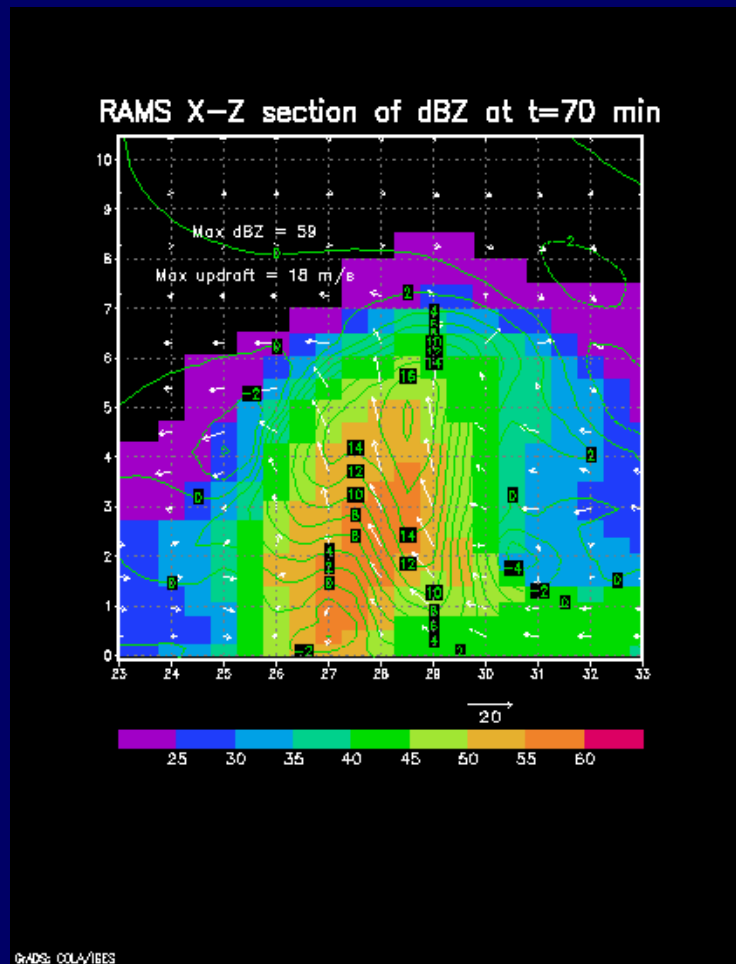
LTG Threat Methodology: Disadvantages

- Methods are only as good as the numerical model output; models usually do not make storms in the right place at the right time; saves at 15 min sometimes miss LTG jump peaks
- Small number of cases, lack of extreme LTG events means uncertainty in calibrations
- Calibrations should be redone whenever model is changed (see example next page; pending studies of sensitivity to grid mesh, model microphysics, to be addressed here)

RAMS example showing sensitivity to mesh, physics (data from 10 Dec 2004 cool-season storm case)

Sample output from
RAMS model, using:

- 500 m mesh in x,y
- 5 precip species
- idealized initialization
(warm bubble)
- wmax is roughly twice
that produced by WRF
on 2 km mesh





WRF Configuration (typical)

30 March 2002 Case Study

- 2-km horizontal grid mesh
- 51 vertical sigma levels
- Dynamics and physics:
 - Eulerian mass core
 - Dudhia SW radiation
 - RRTM LW radiation
 - YSU PBL scheme
 - Noah LSM
 - WSM 6-class microphysics scheme (graupel; no hail)
- 8h forecast initialized at 00 UTC 30 March 2002 with AWIP212 NCEP EDAS analysis;
- Also used METAR, ACARS, and WSR-88D radial vel at 00 UTC;
- Eta 3-h forecasts used for LBC's



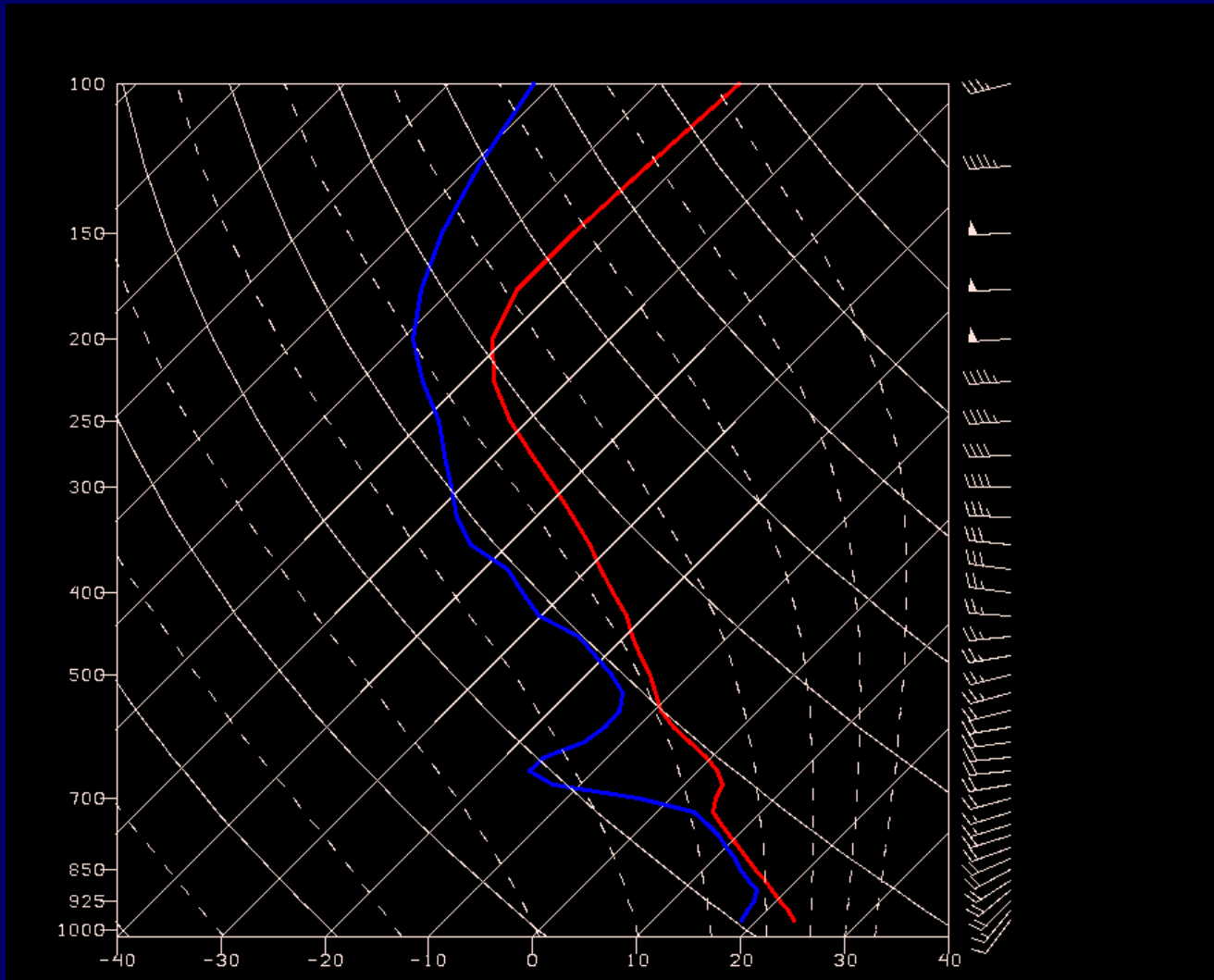
WRF Lightning Threat Forecasts:

Case: 30 March 2002

Squall Line plus Isolated Supercell



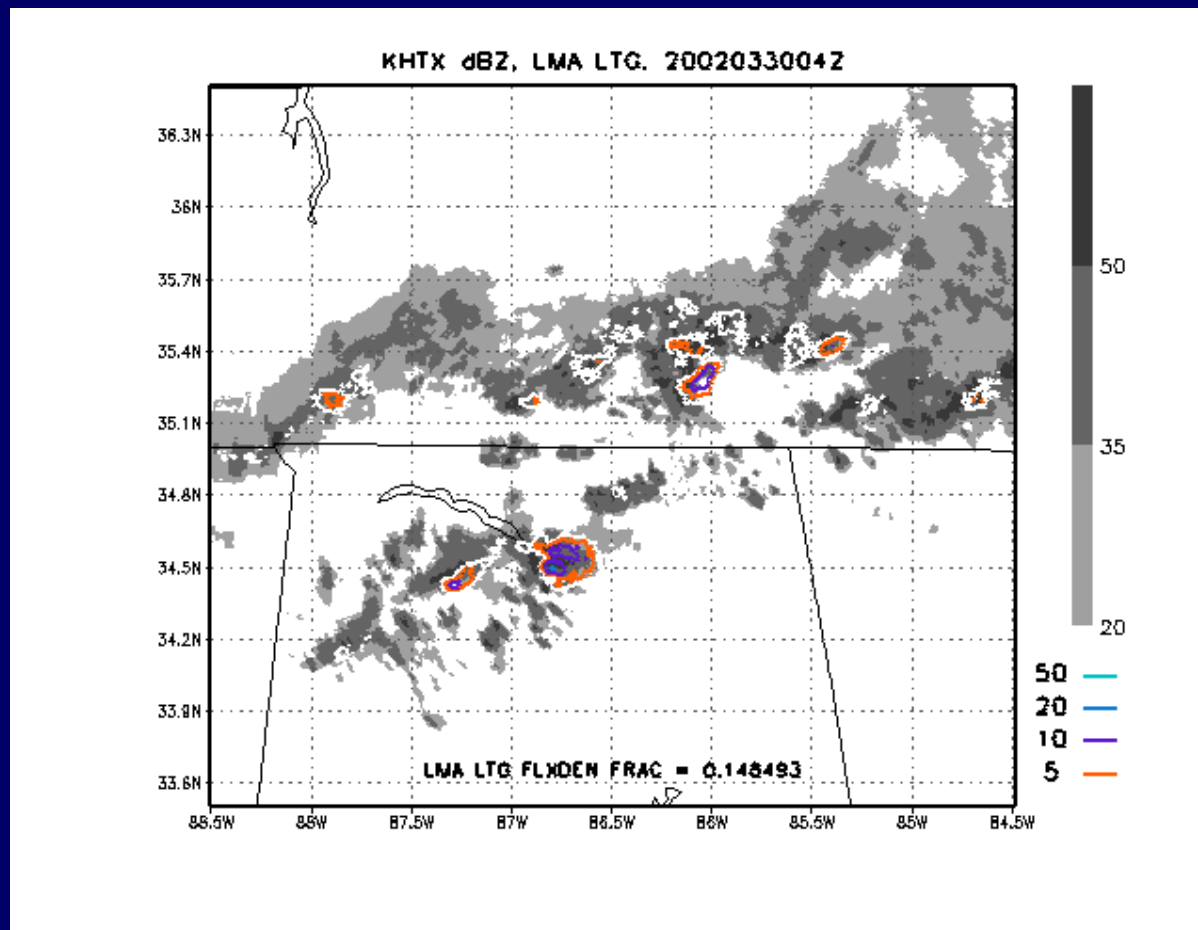
WRF Sounding, 2002033003Z



Lat=34.4
Lon=-88.1
CAPE~2800

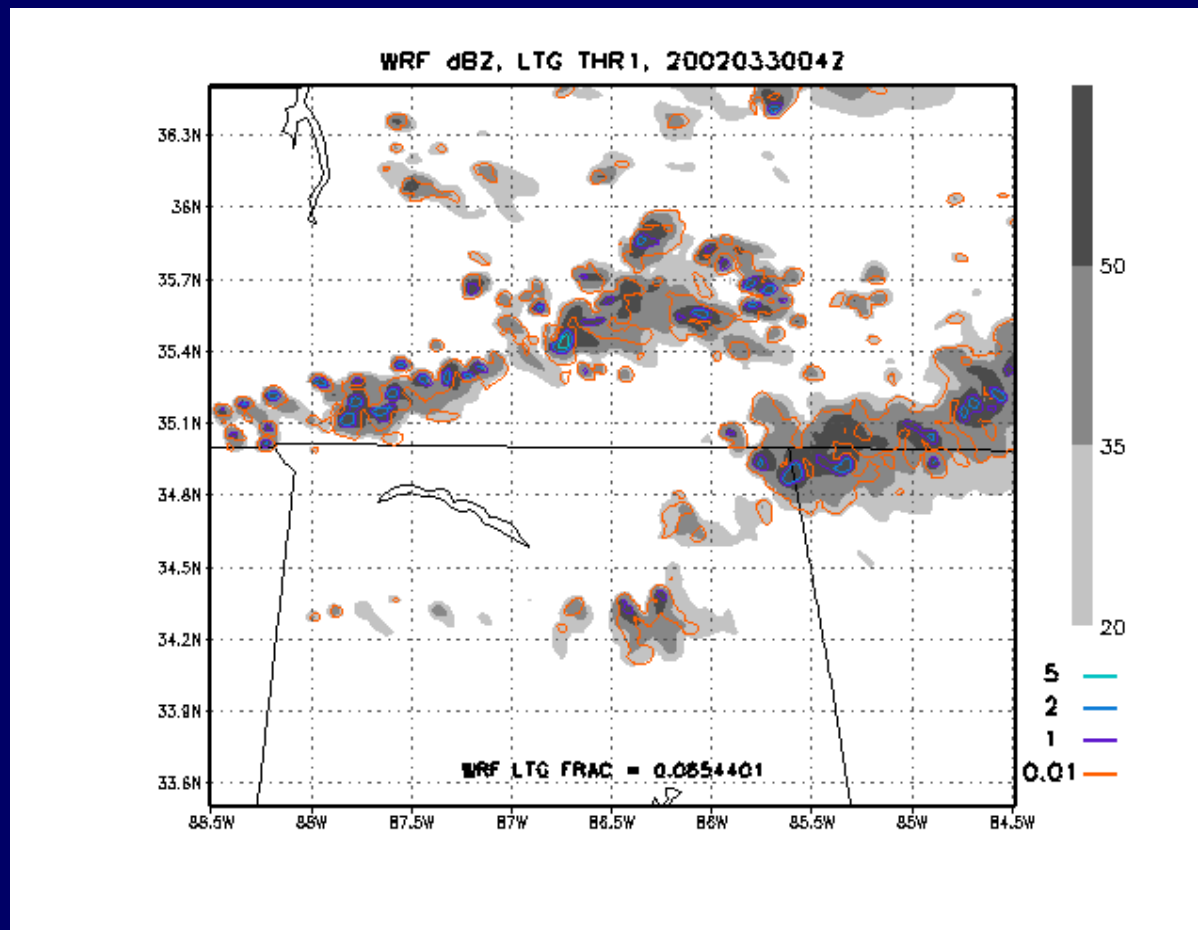
Ground truth: LTG flash extent density + dBZ

30 March 2002, 04Z



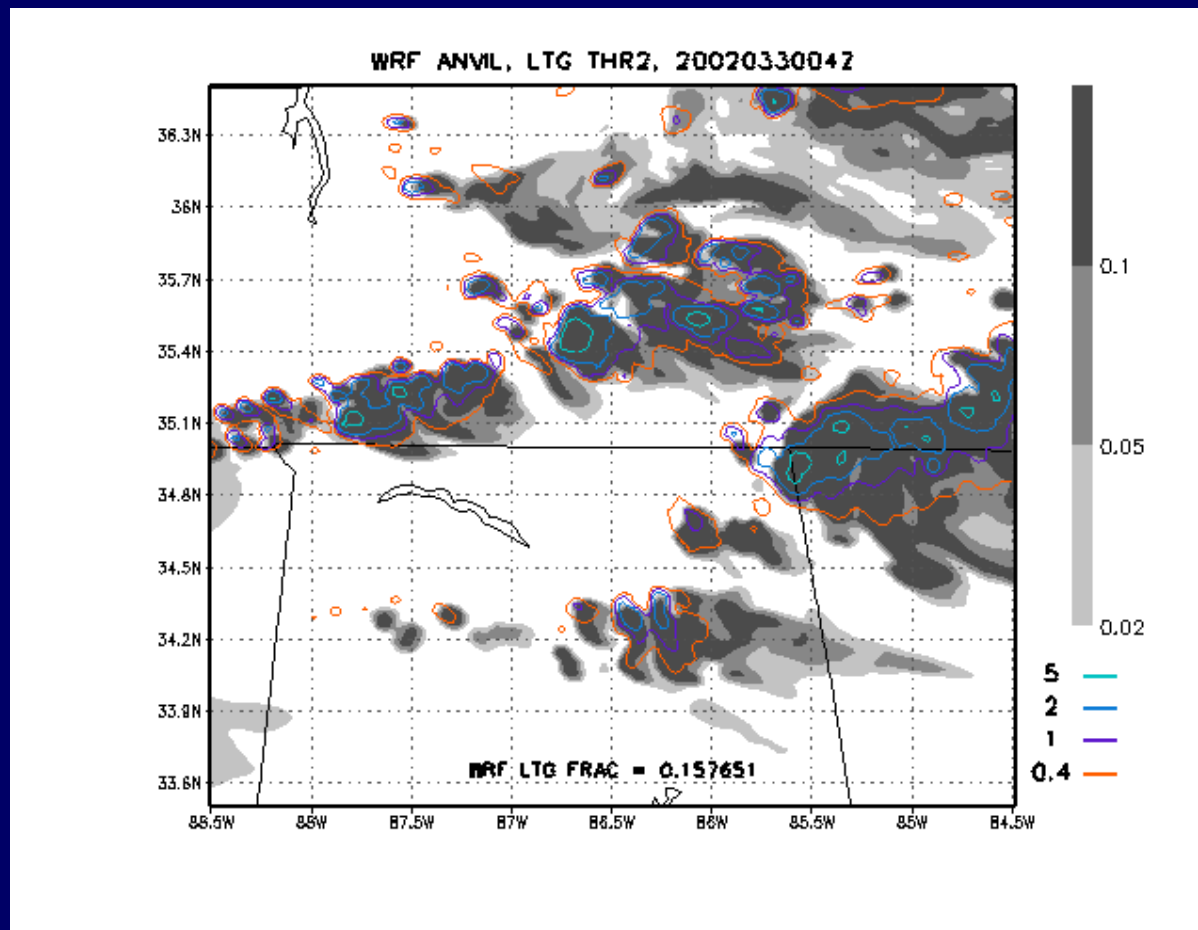
WRF forecast: LTG Threat 1 + 6km dBZ

30 March 2002, 04Z

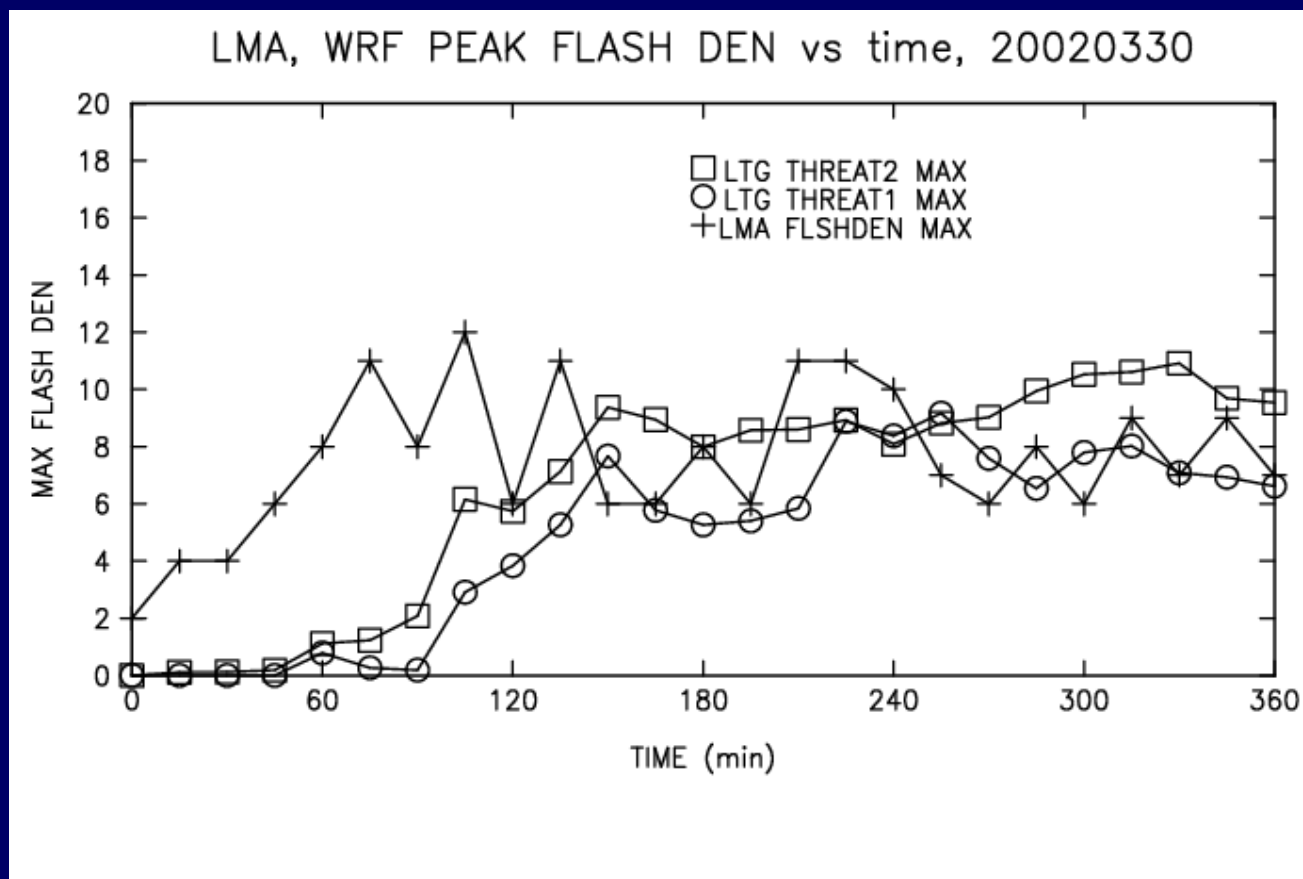


WRF forecast: LTG Threat 2 + 10 km anvil ice

30 March 2002, 04Z



Domainwide Peak Flash Density Time Series 30 March 2002



Note smaller t variability of Threat 2 compared to Threat 1 and LMA

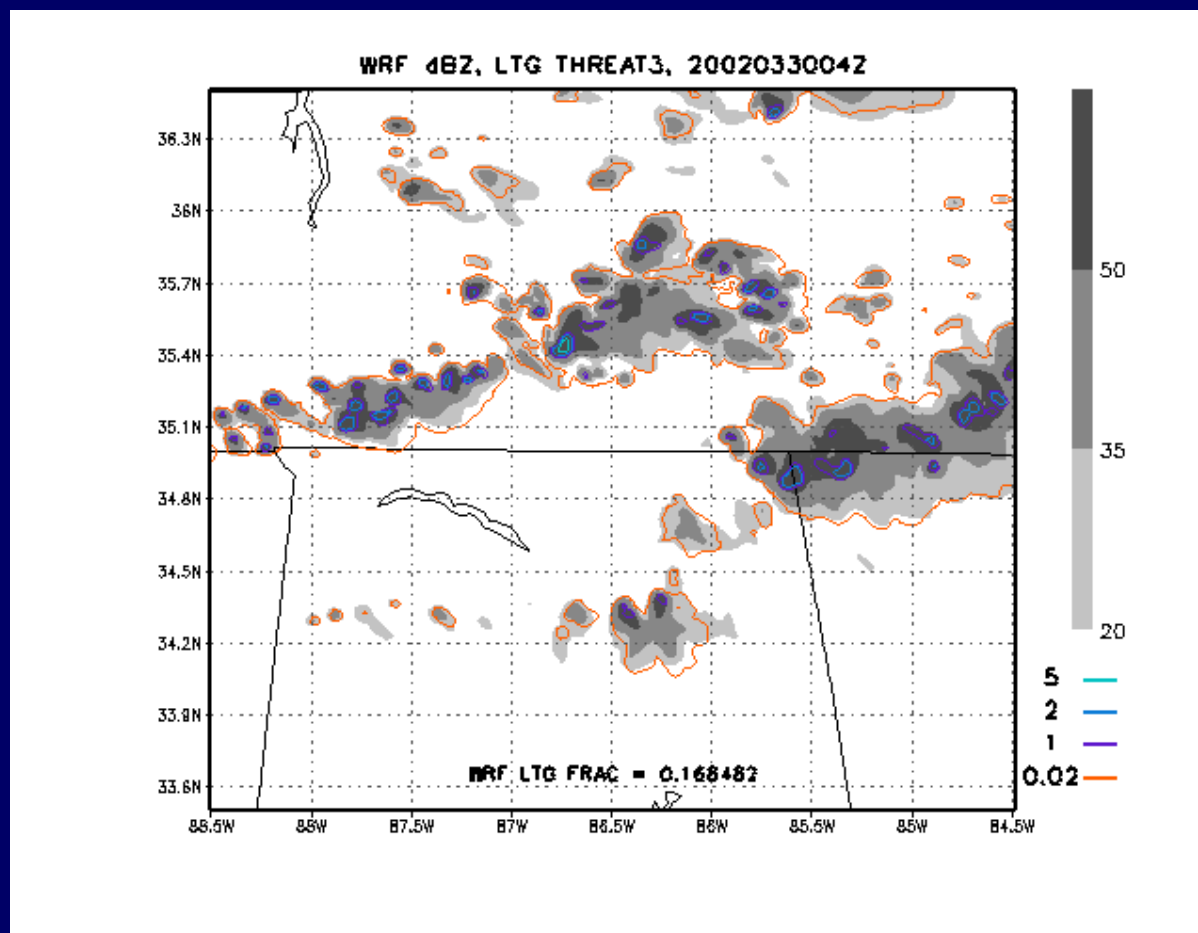
Implications of results:

1. WRF LTG threat 1 coverage too small (updrafts emphasized)
2. WRF LTG threat 1 peak values have adequate t variability
3. WRF LTG threat 2 peak values have insufficient t variability (because of smoothing effect of z integration)
4. WRF LTG threat 2 coverage is good (anvil ice included)
5. WRF LTG threat mean biases can exist because our method of calibrating was designed to capture *peak* flash rates, not *mean* flash rates
6. Blend of WRF LTG threats 1 and 2 should offer good time variability, good areal coverage

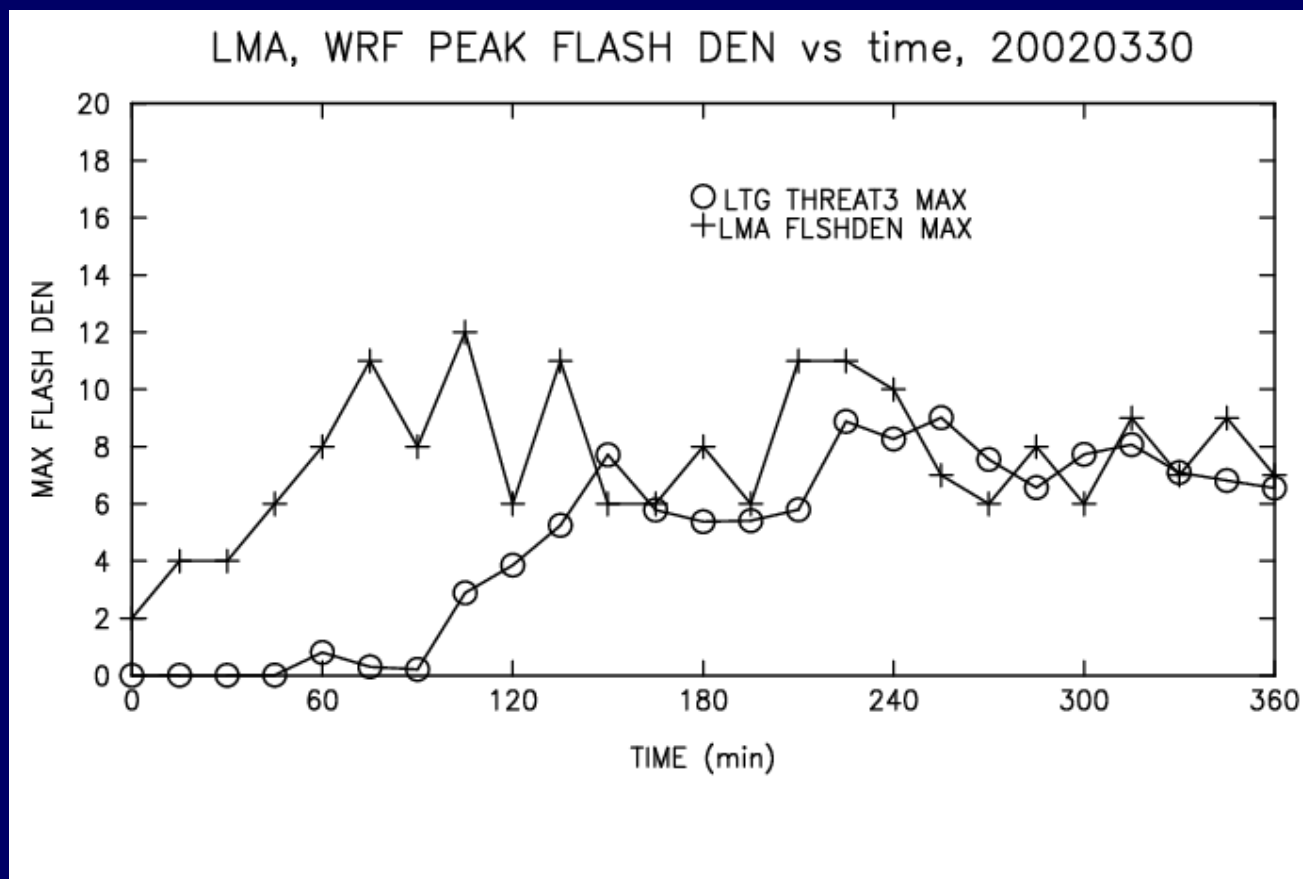
Construction of blended threat:

1. Threat 1 and 2 are both calibrated to yield correct peak flash densities
2. The peaks of threats 1 and 2 also tend to be coincident in all simulated storms, but threat 2 covers more area
3. Thus, weighted linear combinations of the 2 threats will also yield the correct peak flash densities
4. To preserve most of time variability in threat 1, use large weight w_1
5. To preserve areal coverage from threat 2, avoid very small weight w_2
6. Tests using 0.95 for w_1 , 0.05 for w_2 , yield satisfactory results

Blended Threat 3 + dBZ: 2002033004Z



Domainwide Blended Threat Time Series



Note Threat 3 retains most of t variability of Threat 1

General Findings:

1. LTG threats 1 and 2 yield reasonable peak flash rates
2. LTG threats provide more realistic spatial coverage of LTG than that suggested by coverage of positive CAPE, which overpredicts threat area, especially in summer
 - in AL cases, CAPE coverage ~60% at any t, but our LFA, NALMA obs show storm coverage only ~15%
 - in summer in AL, CAPE coverage almost 100%, but storm time-integrated coverage only ~10-30%
 - in frontal cases in AL, CAPE coverage 88-100%, but squall line storm time-integrated coverage is 50-80%
3. Blended threat retains proper peak flash rate densities, because constituents are calibrated and coincident
4. Blended threat retains temporal variability of LTG threat 1, and offers proper areal coverage, thanks to threat 2



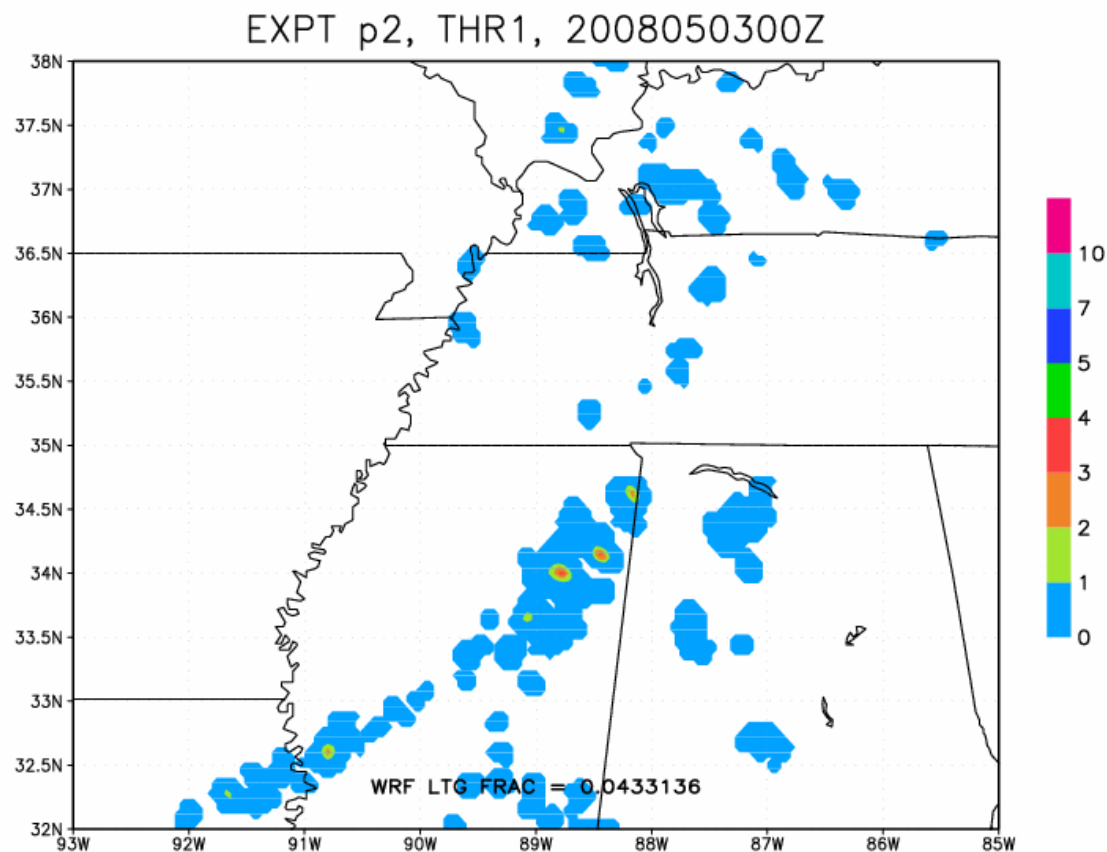
Ensemble studies, CAPS cases, 2008:

(examined to test robustness under varying grids, physics)

1. Examined CAPS ensemble output for two AL-area storm events from Spring 2008: 2 May and 11 May
2. NALMA data examined for both cases to check LFA
3. Caveats based on data limitations:
 - CAPS grid mesh 4 km, whereas LFA trained on 2 km mesh
 - model output saved only hourly; no peak threats available
 - to check calibrations, use mean of 12 NALMA 5-min peaks
4. Results from 10 CAPS ensemble members, 2 cases:
 - Threat 1 always smaller than Threat 2, usually 10-20%
 - Threat 2 values look reasonable compared to NALMA
 - Threat 1 shows more sensitivity to grid change than Threat 2

CAPS p2, Threat 1: 2008050300Z

(Member p2 chosen for its resemblance to original WRF configuration)

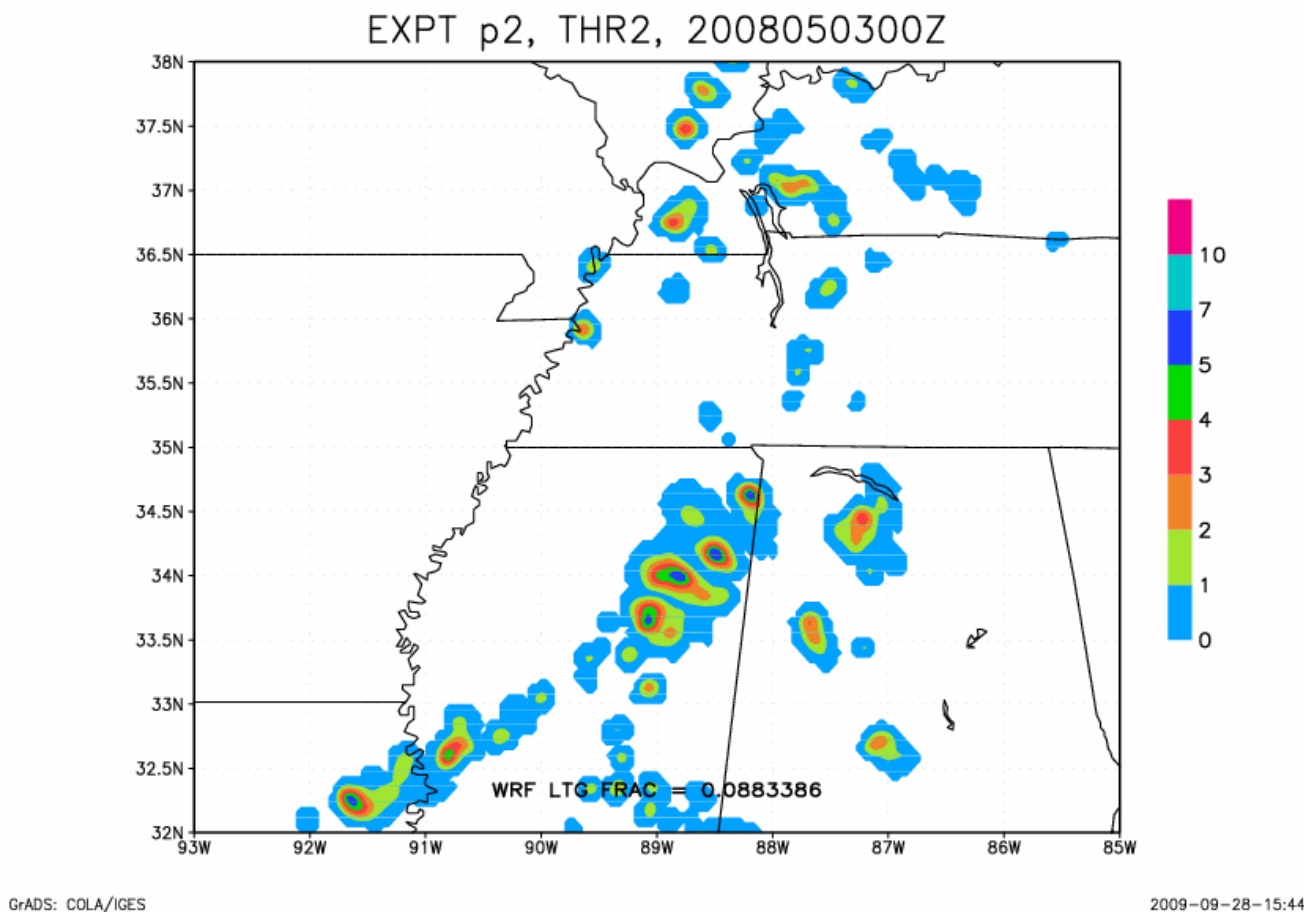


GrADS: COLA/IGES

2009-09-28-15:42

CAPS p2, Threat 2: 2008050300Z

(Note greater amplitude and coverage of Threat 2 vs. Threat 1)



General conclusions:

1. LTG threats 1 and 2 yield reasonable peak flash rates, but with some sensitivity to mesh, physics changes
2. LTG threats provide more realistic spatial coverage of LTG than that suggested by coverage of CAPE, LI, which overpredict threat, especially in summer
3. Blended threat retains proper peak flash rate densities, if constituents are calibrated and coincident
4. Blended threat retains temporal variability of LTG threat 1, but offers adequate areal coverage, thanks to threat 2



Ensemble findings (preliminary):

1. Tested LFA on two CAPS 2008 4km WRF runs
2. Two cases yield consistent, similar results
3. Results sensitive to coarser grid mesh, model physics
 - Threat 1 too small, more sensitive (grid mesh sensitivity?)
 - Threat 2 appears less sensitive to model changes
 - Remedy: boost Threat 1 to equal Threat 2 peak values before creating blended Threat 3
4. Implemented modified LFA in NSSL WRF 4 km runs in 2010



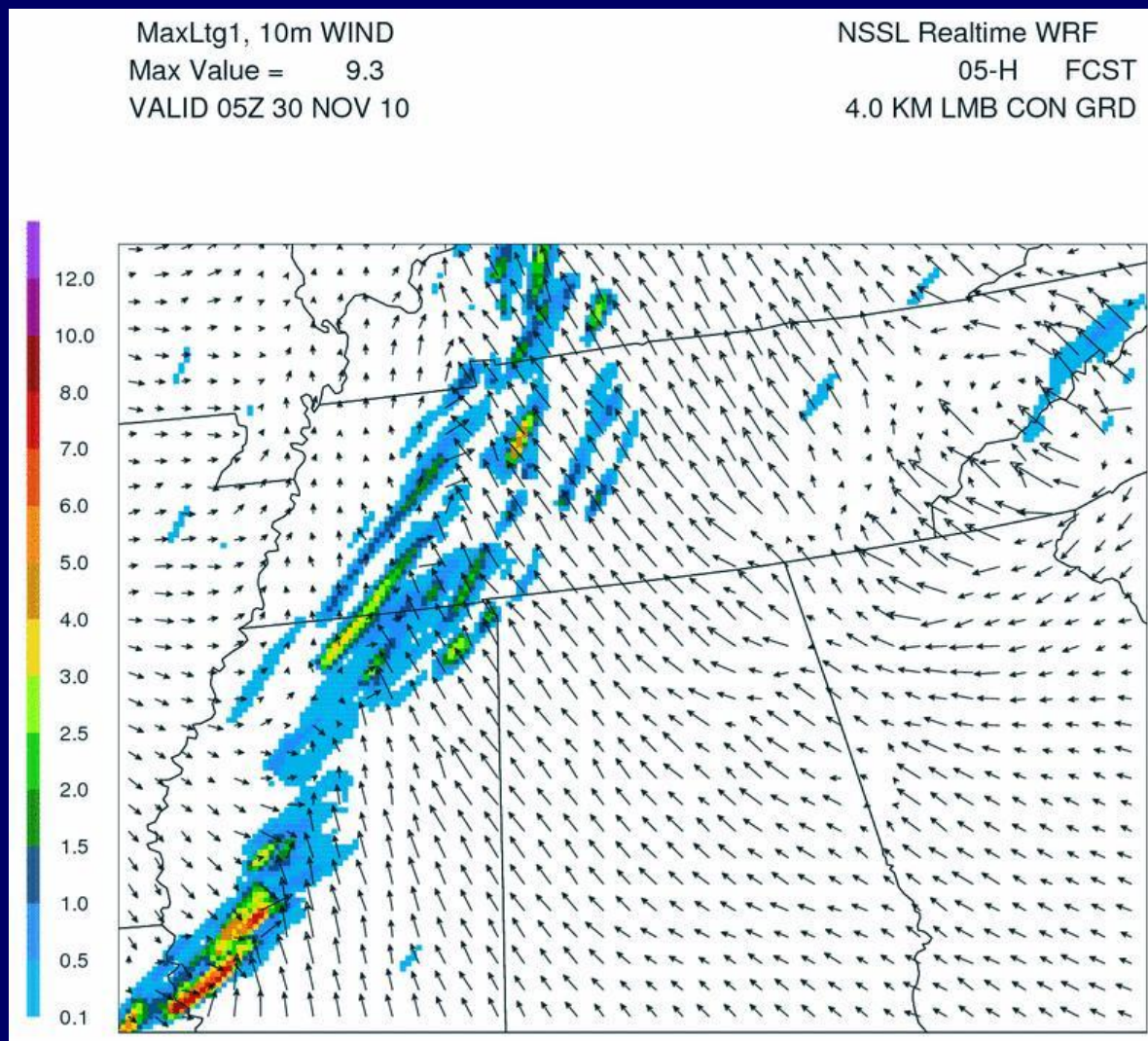
2010 work with NSSL WRF:

1. LFA now used routinely on NSSL WRF 30-h runs
2. See www.nssl.noaa.gov/wrf and look for Threat plots
3. Results are expressed in terms of hourly gridded maxima for threats 1, 2, *before* rescaling of threat 1; units are flashes per sq. km per 5 min
4. To make blended threat 3, we use fields of hourly maxima of threats 1,2, after appropriate rescaling of threat 1
5. Potential issues: in snow events, can have spurious threat 2; in extreme storms, threat 2 fails to keep up with threat 1, even though coarser grid argues for need to boost threat 1; further study needed
6. NSSL collaborators, led by Jack Kain, tested LFA reliability against existing LTG forecast tools, with favorable findings



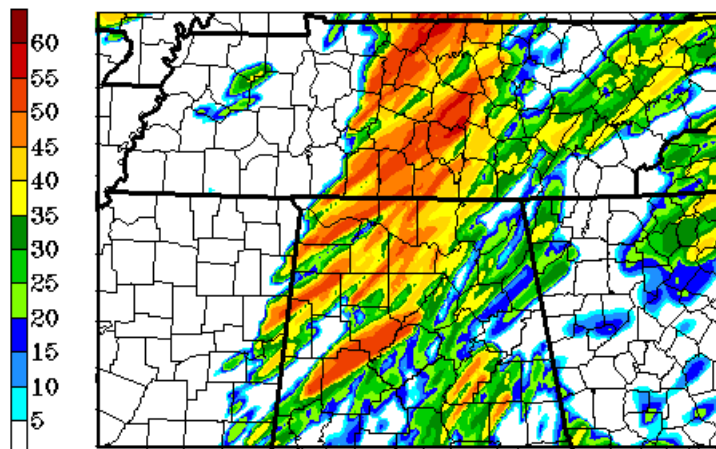
Sample of NSSL WRF output, 20101130

(see www.nssl.noaa.gov/wrf)



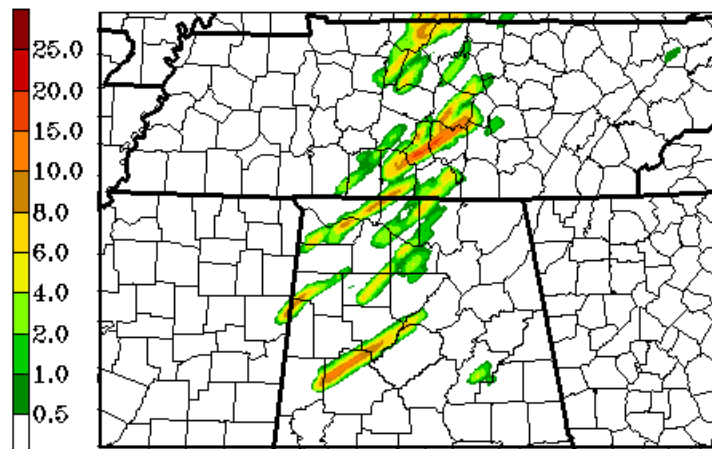
NSSL WRF data: 24 April 2010

Mx Hrly 1km dBZ valid 100424/2200V022



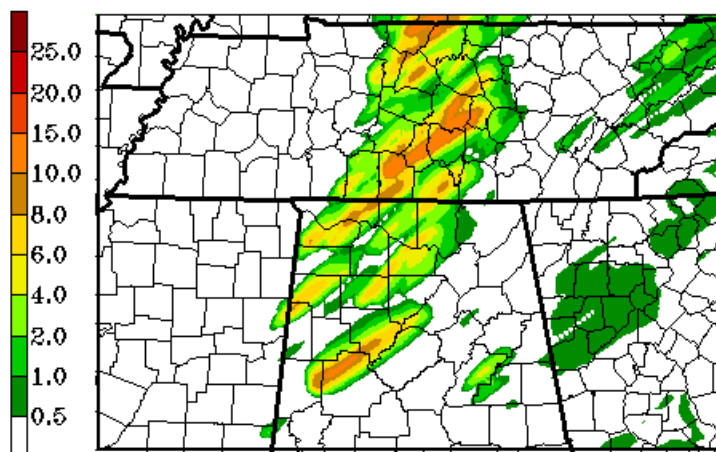
MaxVal=56.75

Mx Hrly LTG Threat 1 (Gr. flux)



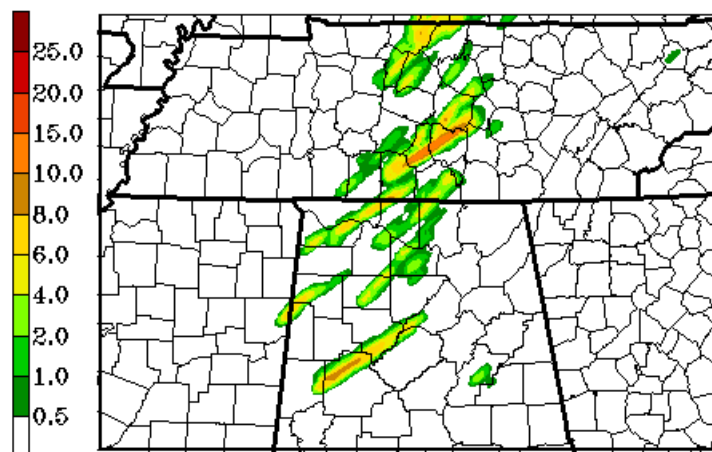
MaxVal=16.25

Mx Hrly LTG Threat 2 (Vert. Int. Ice)



MaxVal=12.75

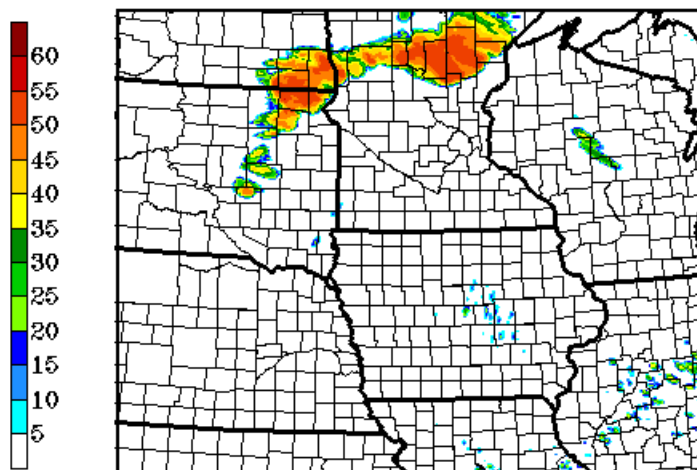
Mx Hrly LTG Threat 3 (Blend)



MaxVal=12.75

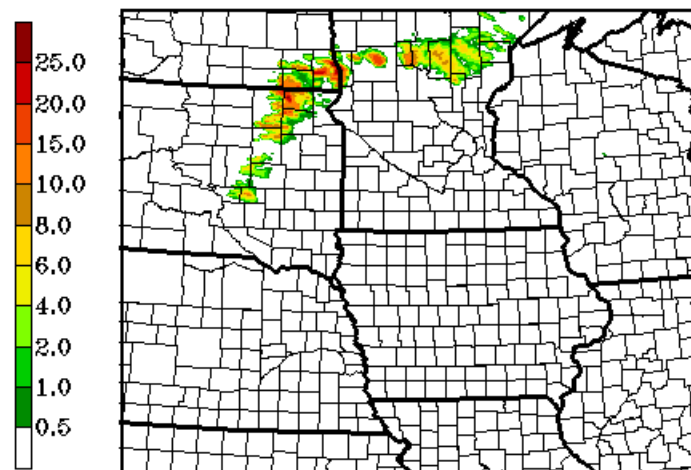
NSSL WRF output: 17 July 2010

Mx Hrly 1km dBZ valid 100717/2200V022



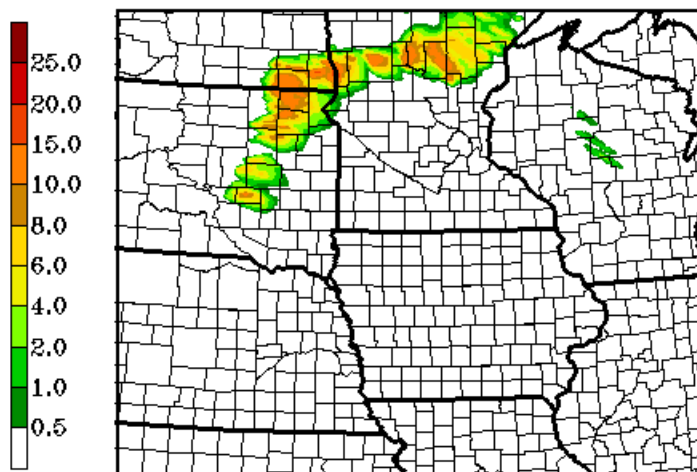
MaxVal=55.31

Mx Hrly LTG Threat 1 (Gr. flux)



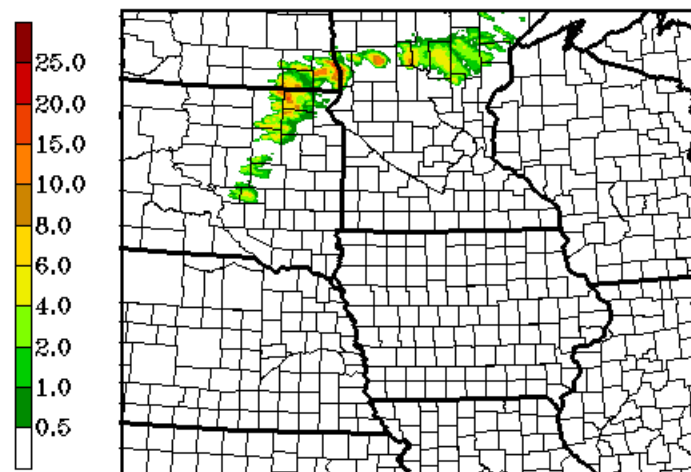
MaxVal=30.88

Mx Hrly LTG Threat 2 (Vert. Int. Ice)



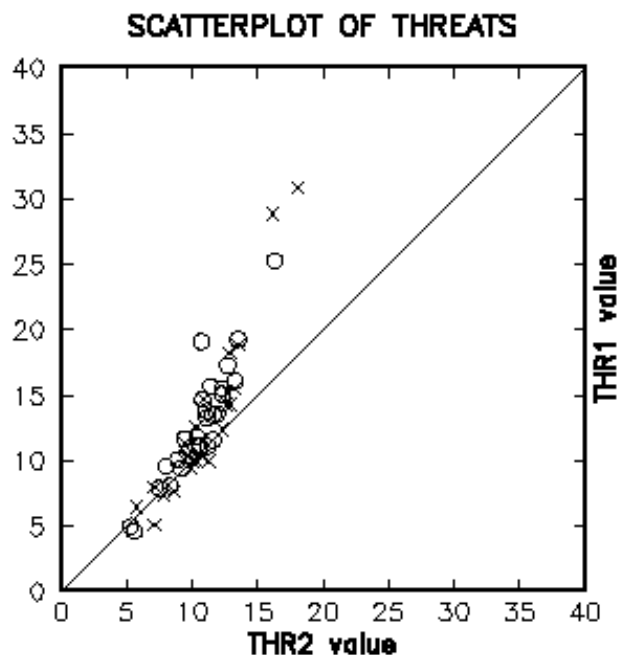
MaxVal=18.06

Mx Hrly LTG Threat 3 (Blend)



MaxVal=17.94

Scatterplot of selected NSSL WRF output for threats 1, 2 (for internal consistency)



Threats 1, 2 should cluster along diagonal; deviation at high flash rates indicates need for recalibration



Future Work:

1. Examine more simulation cases from 2010 Spring Expt; test LFA against dry summer LTG storms in w USA
2. Compile list of intense storm cases, and use NALMA, OKLMA data to recheck calibration curves for nonlinear effects; test for sensitivity to additional storm parameters
3. Run LFA in CAPS 2011 ensembles, assess performance;
 - evaluate LFA in other configurations of WRF ARW
 - more hydrometeor species
 - double-moment microphysics
4. LFA threat fields may offer opportunities for devising data assimilation strategies based on observed total LTG, from both ground-based and satellite systems (GLM)



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McCaul, E. W., Jr., S. J. Goodman, K. LaCasse and D. Cecil, 2009: Forecasting lightning threat using cloud-resolving model simulations. Wea. Forecasting, 24, 709-729.